AD NUMBER

AD849540

NEW LIMITATION CHANGE

TO

Approved for public release, distribution unlimited

FROM

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; Sep 1968. Other requests shall be referred to Department of Defense, Armed Services Explosives Safety Board, Washington, DC.

AUTHORITY

USNWC ltr, 30 Aug 1974

AD849540

NWC TP 4643

HIGH EXPLOSIVE EQUIVALENCY TESTS OF LARGE SOLID PROPELLANT MOTORS

by

URS Systems Corporation
for the
Systems Development Department

ABSTRACT. From June 1965 to February 1968, nine solid propellant motor hazard tests and six high-explosive tests were conducted at the Naval Weapons Center, China Lake, to evaluate the explosive potential of large Class 2 and Class 7 solid propellant motors. Test parameters which were varied during the program were propellant type, weight, and orientation and explosive booster type and location. The results of these tests, combined with data from seven previous tests conducted at NWC, indicate that, under the stimulus of a relatively small (50 to 100 lb) explosive booster, the Class 7 motors tested are capable of producing blast yields averaging 130% of TNT, and the Class 2 motors produced yields as large as 40%. When a Class 7 motor with an explosive booster was placed in intimate contact with a Class 2 motor, yields, based on the total propellant weight, ranged from 105 to 123%. The estimated yields for the Class 2 motors alone ranged from 87 to 119%. In tests in which a Class 7 motor with an explosive booster was placed near, but not in intimate contact with, a Class 2 motor, the estimated yields for the Class 2 motors alone ranged from 30 to 50%, considerably lower than the yields obtained in the intimate-contact tests. The separation distances used ranged from 3 to 18 inches.

NAVAL WEAPONS CENTER
CHINA LAKE, CALIFORNIA * SEPTEMBER 1968

51

NAVAL WEAPONS CENTER
AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

M. R. Etheridge, Capt., USN .... Commander
Thomas S. Amlie, Ph.D. .... Technical Director

FOREWORD

This report presents data obtained from nine motor-hazard tests of Class 7 and Class 2 solid propellant motors and six high-explosive tests, conducted as part of a continuing series of hazard investigations being performed at NWC for the Armed Services Explosives Safety Board. Funding was provided by the Army, Navy, Air Force, Defense Atomic Support Agency, and the National Aeronautics and Space Administration.

Results of the tests, which were conducted during the period June 1965 through February 1968, have been combined with the data obtained in seven earlier tests (NOTS TP 3910) to determine the TNT explosive equivalency of large solid propellant motors.

This report was prepared for the Naval Weapons Center by the URS Systems Corp., Burlingame, California, under a contract that called for the reduction and analysis of data furnished by NWC and the documentation of the results. Only minor editorial and format changes have been made to comply with the publishing policies of the Center.

Released by
J. E. COLVARD, Head
Range Operations Division
6 August 1968

Under authority of
IVAR E. HIGHBERG, Head
Systems Development Department

NWC Technical Publication 4643

Published by	Systems Development Department
Manuscript	30/MS 9-17
Collation	Cover, 24 leaves, DD Form 1473, abstract cards
First printing	150 unnumbered copies
Security classification	UNCLASSIFIED

CONTENTS

BLANK PAGE

Tables:

INTRODUCTION

This report presents the data from nine propellant and six TNT high explosive tests conducted to evaluate the explosive potential of large Class 2 and Class 7 solid-propellant Minuteman and Polaris missile motors. The tests are part of a continuing series of solid-propellant motor hazard tests being conducted at the Naval Weapons Center, under the auspices of the Armed Services Explosive Safety Board (ASESB).

Seven previous tests, conducted in late 1964 and early 1965, are described in Ref. 1. The results of those tests indicated that under the stimulus of a strong explosive booster, the Class 7 propellant motors tested were capable of producing blast yields exceeding that of TNT, with the Class 2 propellant motors also being capable of producing significant blast yields. In the majority of these early tests, the explosive boosters were placed in the grain perforation in the propellant, which tended to maximize the opportunity for a high-order detonation.

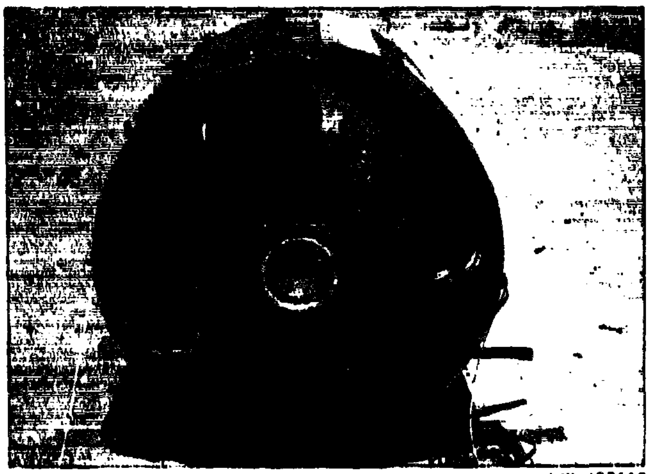
MOTOR TESTS

Motor tests 8 through 16, described in this report, were of the same general type as the seven earlier tests, except that emphasis was placed on more credible donor-acceptor geometries, in which the explosive boosters were placed external to the motors. Test configurations and parameters, plus estimated yield are listed in Table 1 under test results, page 12.

For tests 8*, 9, and 12, the solid propellant motors were placed horizontally, and the explosive boosters were placed directly in the grain perforation of the propellant. Photographs of these test configurations are shown in Fig. 1. In test No. 8, two second-stage Polaris motors, each containing 7,250 lb of Class 2 propellant, were positioned side by side in contact with each other, and

*Tests 1 through 7 were conducted in an earlier series described in Ref. 1; a summary of the results of the earlier tests, using the same criteria as were used in Table 1, is presented in Table 2, page 19.

LHL 108978



LHL 107440

LHL 112471

FIG. 1. Test Configurations for Tests 8, 9, and 12.

a 48-lb charge of Aerex* was placed in the grain of the propellant of each motor. A single third-stage Minuteman motor with 3,665 lb of Class 7 propellant and a 48-lb C-4 booster was used in test No. 9, and test No. 12 consisted of an unprimed second-stage Polaris motor with 7,250 lb of Class 2 propellant as an acceptor, in contact with a third-stage Minuteman motor, containing 3,665 lb of Class 7 propellant, used as the donor. The Class 7 motor was primed with a 48-lb C-4 booster placed in the grain perforation.

In tests 10, 11, 13, and 16, solid propellant motors were placed (or stacked) vertically, and the explosive booster was placed external to the motors and on top of the uppermost stage, as shown in Fig. 2. A single third-stage Minuteman motor containing 3,665 lb of Class 7 propellant was used in test No. 10, and two third-stage Minuteman motors, each with 3,665 lb of Class 7 propellant were stacked vertically for test No. 11. A single 50-lb C-4 explosive booster was used in each of the two tests.

In tests 13 and 16, a second-stage Polaris motor with 8,870 lb of Class 7 propellant was placed on top of a first-stage Polaris motor with 15,200 lb of Class 2 propellant. In test No. 13, the normal interstage hardware, which provides a clearance of 14 in. between the closest points on the bulkheads between the two motors, was used; in test No. 16, a shortened interstage was used to separate these parts by only 3 in. A 96-lb C-4 booster was used for each of the tests.

A three-stage, Wing 1 Minuteman missile (Fig. 3) was used in each of tests 14 and 15. The first-stage contained 45,040 lb of Class 2 propellant, the second-stage contained 10,250 lb of Class 2 propellant, and the third-stage contained 3,665 lb of Class 7 propellant. Normal interstage hardware, which provides clearances of 32 in. between the closest points on the bulkhead between the first and second stages and 18 in. between the second and third stages, was used in test No. 14; and in test No. 15, a shortened interstage was used to separate these parts by 8 and 9 in., respectively. A 48-lb C-4 booster was used for each test.

*Manufactured by the Aerojet General Corporation.

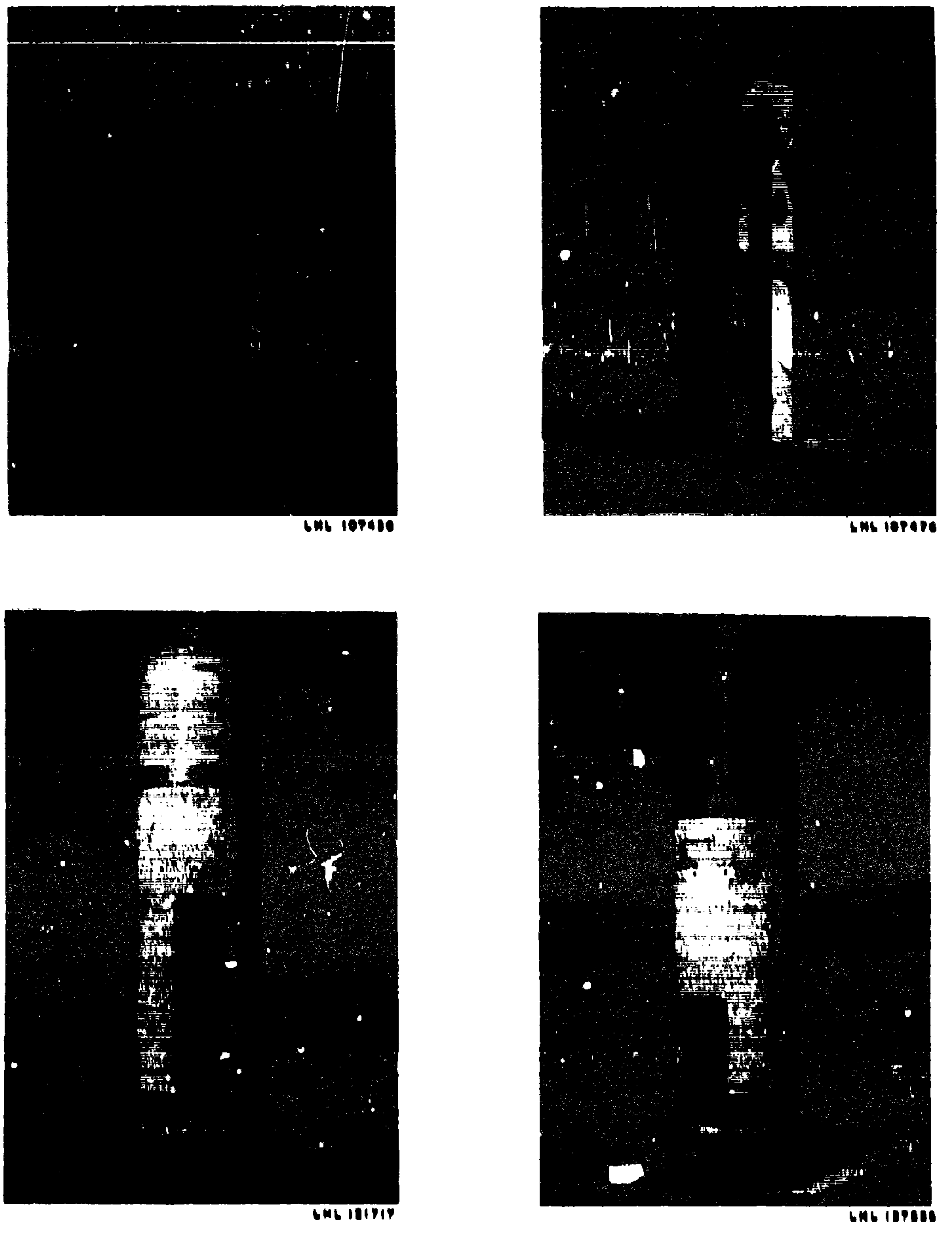
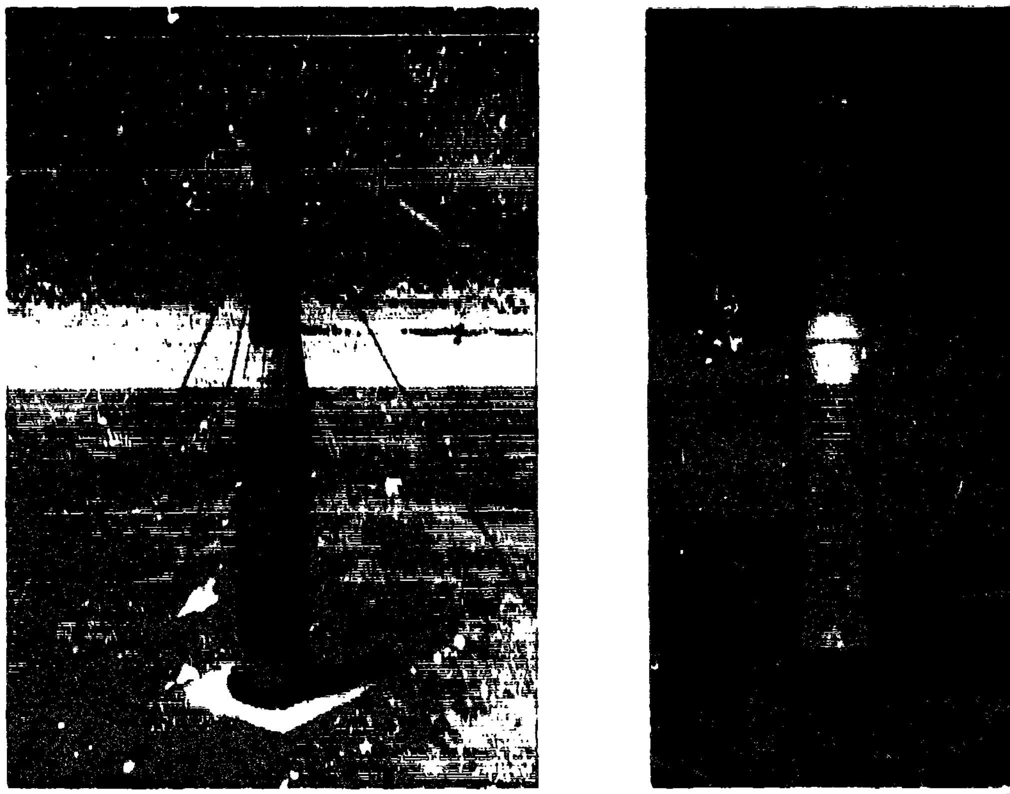


FIG. 2. Test Configurations for Tests 10, 11, 13, and 16.



LHL [illegible] LHL [illegible]

FIG. 3. Test Configurations for Tests 14 and 15.

HIGH EXPLOSIVE TESTS

During this program, six TNT high explosive tests (labeled 1C through 6C to distinguish them from the first series of motor tests) were conducted to check out the blast instrumentation systems and test procedures and to obtain information on the effects of charge geometry on air blast measurements. Photographs of the explosive test configurations are presented in Fig. 4.

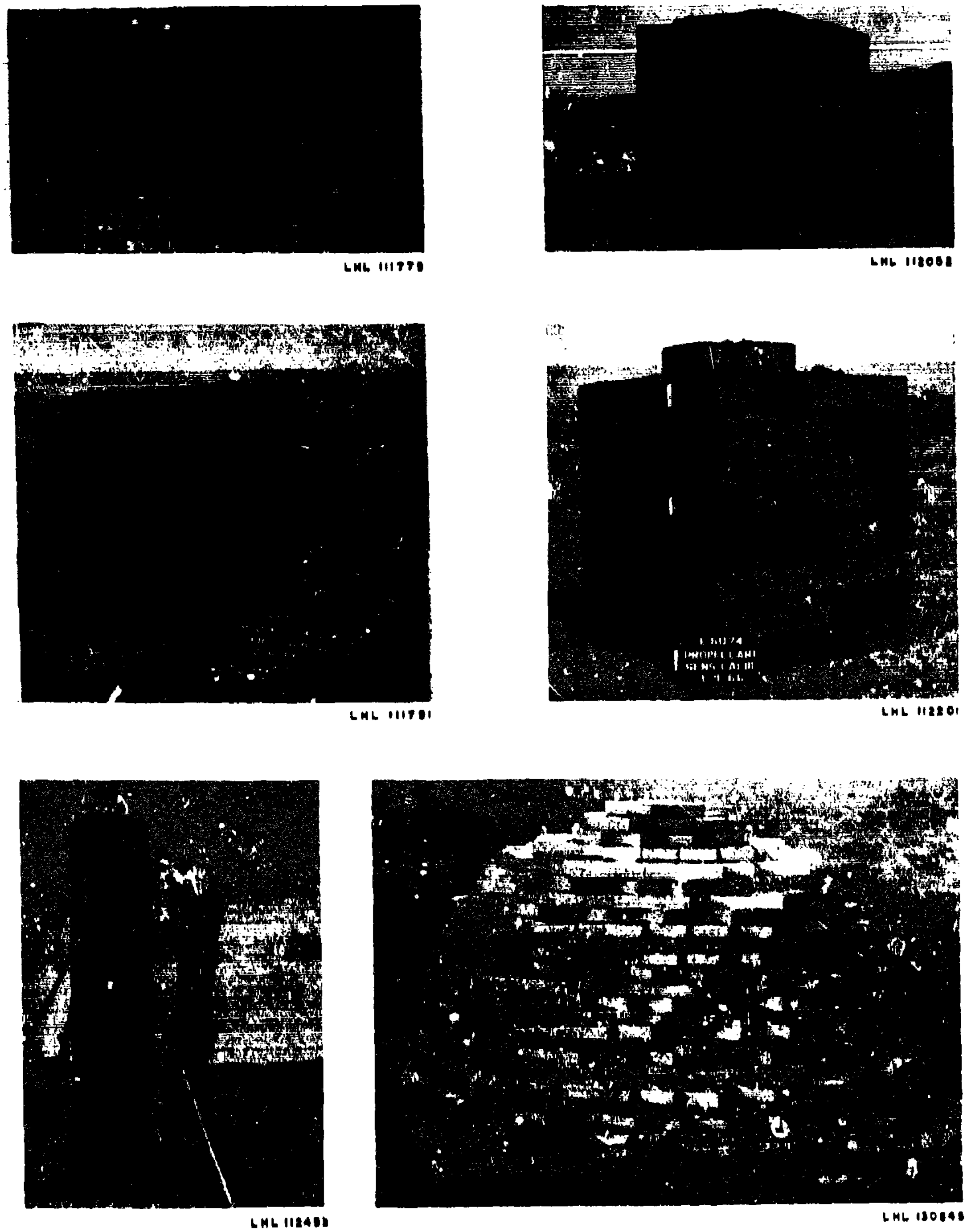


FIG. 4. Test Configurations for Tests 1C, 2C, 3C, 4C, 5C, and 6C.

For tests 1C through 5C, reclaimed TNT was cast in cut-down ammunition boxes with each box containing 50 lb of explosive. In tests 1C, 2C, 3C, and 4C, the boxes were stacked to approximate cubes, with explosive weights of 5,000 lb for test 1C; 20,000 lb for test 2C; and 10,000 lb for tests 3C and 4C. For test 5C, 20,000 lb of TNT was stacked in a configuration approximately 4 ft square and 25 ft high. Test 6C consisted of 10,000 lb of TNT in bare 8-lb blocks stacked in a hemispherical configuration.

TEST LAYOUT AND INSTRUMENTATION

The general test layout and pressure gage station locations are shown graphically in Fig. 5. Not all gage stations shown were used for every test; however, at least one gage was located at each of seven or more different ground ranges on both legs for every test. Four different types of blast gages were used to measure the overpressure-time pulses: Ballistic Research Laboratory (BRL) mechanical PHS gages, BRL mechanical PNS gages, Kistler piezoelectric gages, and Schaevitz-Bytrex piezoresistance gages. Because of the difference in response time, the Kistler and Schaevitz-Bytrex gages were used relatively close in, PNS gages were located at mid-range, and PHS gages were used in the more distant locations.

SUMMARY OF HIGH EXPLOSIVE TEST RESULTS

The individual measured peak overpressure and positive-phase-impulse values obtained from the six high explosive tests are presented in Tables 3 through 17 in the appendix of this report, which also contains posttest photos showing the craters resulting from the explosions and sketches of the crater profiles. The data are summarized in Fig. 6, in which peak overpressure is plotted as a function of scaled distance using reference curves from Ref. 2; and in Fig. 7, in which positive-phase-impulse values are also plotted as a function of scaled distance, using reference curves from Ref. 3. It will be noted that, with the exception of the hemispherical charge data, the close-in test data tend to deviate considerably from the reference curves but, at around 10 psi and below, the agreement is quite good. This departure from the reference curve close to the charge is probably not too surprising considering the nonsymmetrical square and rectangular cross-sectional charge geometries used and the fact that the TNT was cased in wooden boxes.

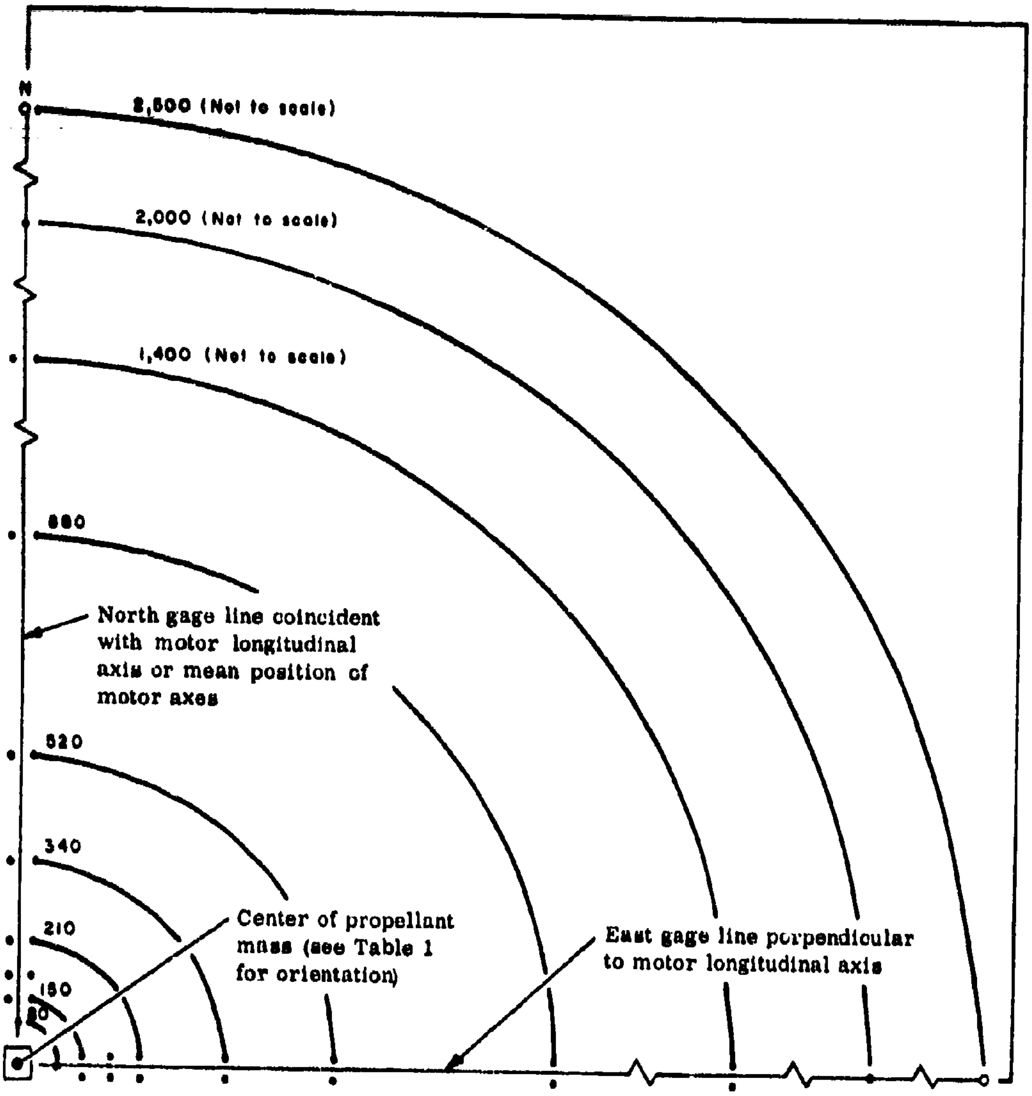


FIG. 5. Overpressure Gage Layout for Motor Hazard Tests.

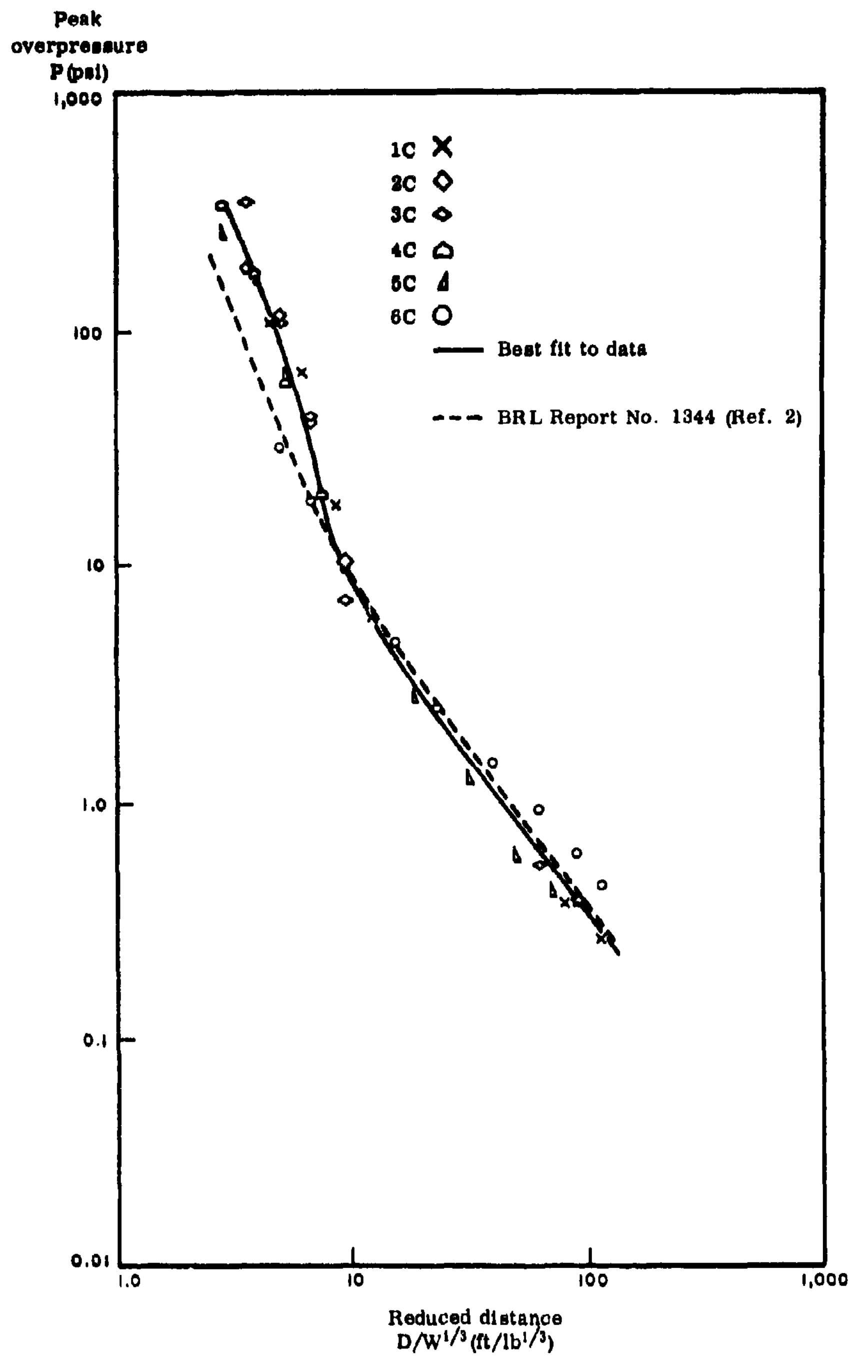


FIG. 6. Summary of Peak Overpressure Data From High Explosive Tests.

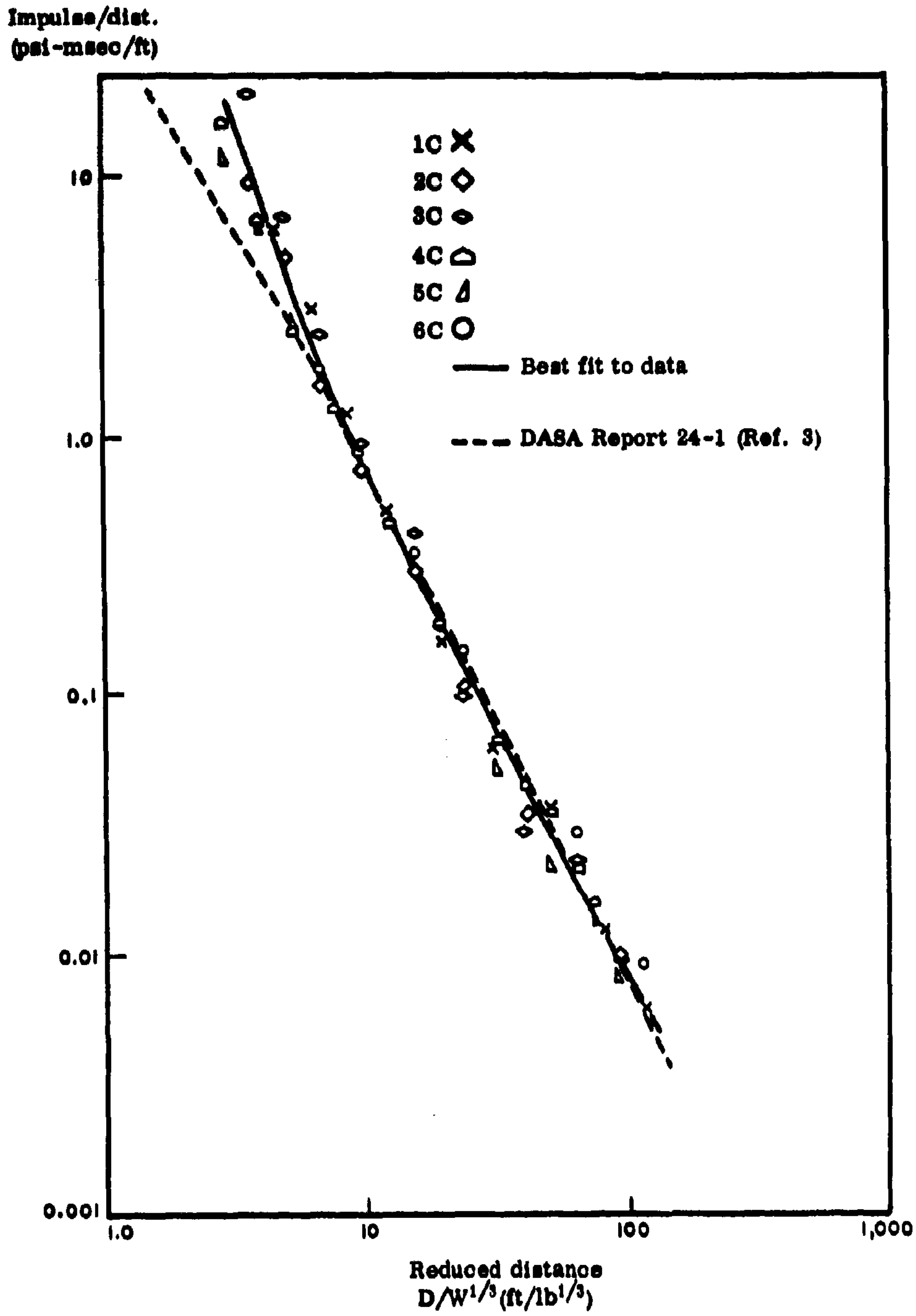


FIG. 7. Summary of Positive-Phase-Impulse Data From High Explosive Tests.

MOTOR HAZARD TEST RESULTS

BLAST DATA

A summary of the nine motor hazard tests conducted during this series is presented in Table 1. The explosive yields, which are expressed relative to TNT, were computed by first finding the weight of TNT that, if put in the same position, would produce the same value of the shock wave parameter (peak overpressure or positive-phase impulse) at the same distance as for the propellant explosion.* This TNT weight was then divided by the total propellant weight** and multiplied by 100 to convert to percent. In many cases, however, the explosive behavior of the propellant mixtures was a function of distance and could not be represented easily by a single value applicable to all distances.

This behavior appeared to take two general forms. For the higher yield tests (> 100%), both the peak overpressure and positive-phase impulse yields tended to decrease with increasing distance, with the yields tending toward a constant value (terminal yield) at long distances. In the lower yield tests (< 100%), the positive-phase impulse yields indicated a similar trend; however, the peak overpressure yields tended to increase with increasing distance. An exception to this was in the tests in which the explosive was centered several charge diameters off the ground surface. In these tests, the peak overpressure yields decreased and the positive-phase impulse yields increased with increasing distance. Because of this yield variation with distance and, occasionally, the variation in the shock wave parameter used in the computation, the following method of data presentation has been adopted. For those tests in which the yields computed from the peak overpressure and positive-phase impulse values tended to seek a constant or terminal value, this number is used. For those motor tests in which the peak overpressure and positive-phase impulse yield values did not reach a constant value within the range of measuring stations used, no terminal yield could be determined, and the value quoted was estimated from the higher of the two yields, either peak overpressure or impulse.

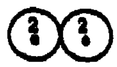
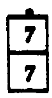
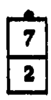
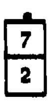
From the individual peak overpressure and positive-phase impulse values for each test presented in the appendix, it will be noted that there was considerable scatter in the data, which affects the reliability of the explosive yield values discussed above. Consequently, the standard deviations of the mean yield values were computed for each test as shown in Table 1.

---

*The reference data used for this computation were obtained from Ref. 2 for peak overpressure and Ref. 3 for positive-phase impulse.

**The booster weights, which range from 48 to 96 lb, were not included in this computation.

TABLE 1. Summary of Tests

Test No.	Test* configuration	Propellant class	Propellant wt (to nearest 5 lb)	Booster	Estimated** yield (%)
8 (ES-5203)		2	14,500	2 - 48 lb Aerex	1.4 ± 0.2 (I)
9 (ES-5276)		7	3,665	1 - 48 lb C-4	125 ± 8 (T)
10 (ES-5277)		7	3,665	1 - 50 lb C-4	120 ± 13 (I)
11 (ES-5278)		7	7,330	1 - 50 lb C-4	124 ± 12 (I)
12 (ES-6068)		2 7	7,250 3,665	1 - 48 lb C-4	105 ± 3 (T)
13 (ES-7040)	 A	7 2	8,870 15,200	1 - 96 lb C-4	73 ± 6 (T)
14 (ES-7125)	 A	7 2 2	3,665 10,250 45,040	1 - 48 lb C-4	13 ± 0.6 (P)
15 (ES-7182)	 B	7 2 2	3,665 10,250 45,040	1 - 48 lb C-4	16.5 ± 1.3 (P)
16 (ES-7217)	 B	7 2	8,870 15,200	1 - 96 lb C-4	82 ± 3 (T)

*A - normal interstage spacing, • - location of booster, B - shortened interstage spacing

**Basis for yield estimate - I-impulse data, P-pressure data, T-both pressure and impulse data (see text). Uncertainty is expressed in terms of the standard deviation of the mean value of the gage readings.

Tests 8, 9, and 12

In these tests, the solid propellant motors were placed with their axes horizontal, and the explosive boosters were placed directly in the grain perforation of the propellant as shown in Fig. 1.

Test 8 consisted of two immediately adjacent second-stage Polaris motors, each containing 7,250 lb of Class 2 propellant and having steel cases. A 48-lb Aerex booster was placed in each motor. In this test, a great deal of burning and unignited fragments of propellant and casing material was scattered over the area, with large pieces of the metal casing being left in and near the crater. Although the crater (Fig. 8) was indicated to be approximately 10 ft in diameter and about 1 ft deep, no profile was given. The volume was estimated as 100 cu ft by assuming the crater profile to be as shown. The estimated terminal yield, based on a total propellant weight of 14,500 lb, was 1.4 percent.

Test 9 was a single third-stage Minuteman motor containing 3,665 lb of Class 7 propellant in a fiberglass casing, and with a 48-lb C-4 booster charge placed in the grain of the propellant. No burning fragments were visible in the films of the test, and no casing fragments were found. The crater shown in Fig. 8 was about 28 ft in diameter, had a maximum depth of 3 ft below the initial ground surface, and had an estimated volume of about 800 cu ft. The estimated terminal yield for this test was 125 percent.

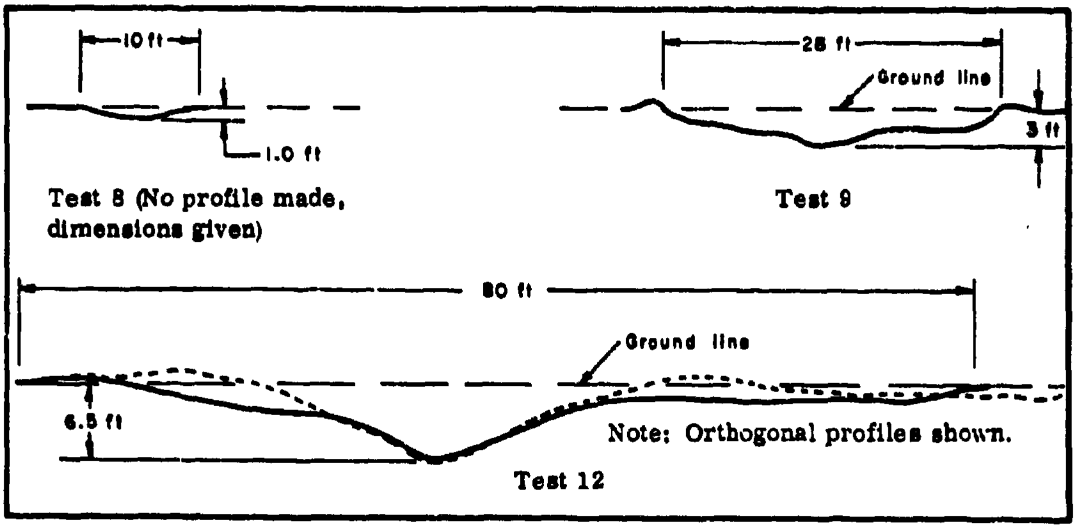


FIG. 8. Crater Profiles for Motor Tests Conducted With Axes Horizontal.

Test 12 consisted of a motor identical to that used in test 9 placed adjacent to, and in contact with, a steel-cased second-stage Polaris motor containing 7,250 lb of Class 2 propellant. As in test 9, no burning fragments of propellant were observed, and no casing fragments were found, even though a search extended to 5,000 ft from ground zero. The crater was the largest produced in this entire series of motor tests, and its maximum diameter was about 70 ft. The estimated volume was 2,600 cu ft; the estimated terminal yield, based on the total propellant weight of 10,915 lb, was 105 percent.

Tests 10, 11, 13, and 16

In these tests the solid propellant motors were placed vertically, and the explosive boosters were placed external to the motors and on the uppermost stage.

Test 10 used a single third-stage Minuteman motor containing 3,665 lb of Class 7 propellant with a 50-lb C-4 booster placed on top of the motor. With the exception of this external booster and the vertical orientation of the motor axis, this test was similar to test 9. No burning fragments of propellant were observed, and no casing fragments were found. The crater (Fig. 9) was about 28 ft in diameter, the maximum depth was approximately 3 ft, and the volume was on the order of 700 cu ft. The estimated impulse yield was approximately 120 percent, or almost the same yield as obtained in test 9. The crater volumes were also comparable.

In test 11, two Class 7 motors were stacked vertically, with the upper one acting as the donor and the lower one as the acceptor; i.e., only the upper motor was primed with a C-4 booster (see Table 1). Again, no fragments were observed. The approximate crater dimensions were 28 ft diameter and 4 ft depth (Fig. 9). The estimated volume was 800 cu ft; the estimated impulse yield, based on a total propellant weight of 7,330 lb, was approximately 124 percent, or essentially the same as for test 10. Though the effective TNT weight (and the actual propellant weight) was twice that of test 10, the crater volume was only slightly larger. This is not too surprising since the effective scaled height of the explosion burst was at least twice as large as for test 10.

In test 13, a second-stage Polaris motor containing 8,870 lb of Class 7 propellant was placed on top of a first-stage Polaris motor with 15,200 lb of Class 2 propellant, using normal interstage hardware with nozzles which provided a clearance of 14 in. between the closest points on the bulkheads. In this test, burning propellant was scattered over a wide area and pieces of unburned propellant were found out to 1,800 ft. Motor parts were found at distances out to 2,500 ft. No significant crater was formed (Fig. 9), and the estimated terminal yield, based on a total propellant weight of 24,070, was 73 percent.

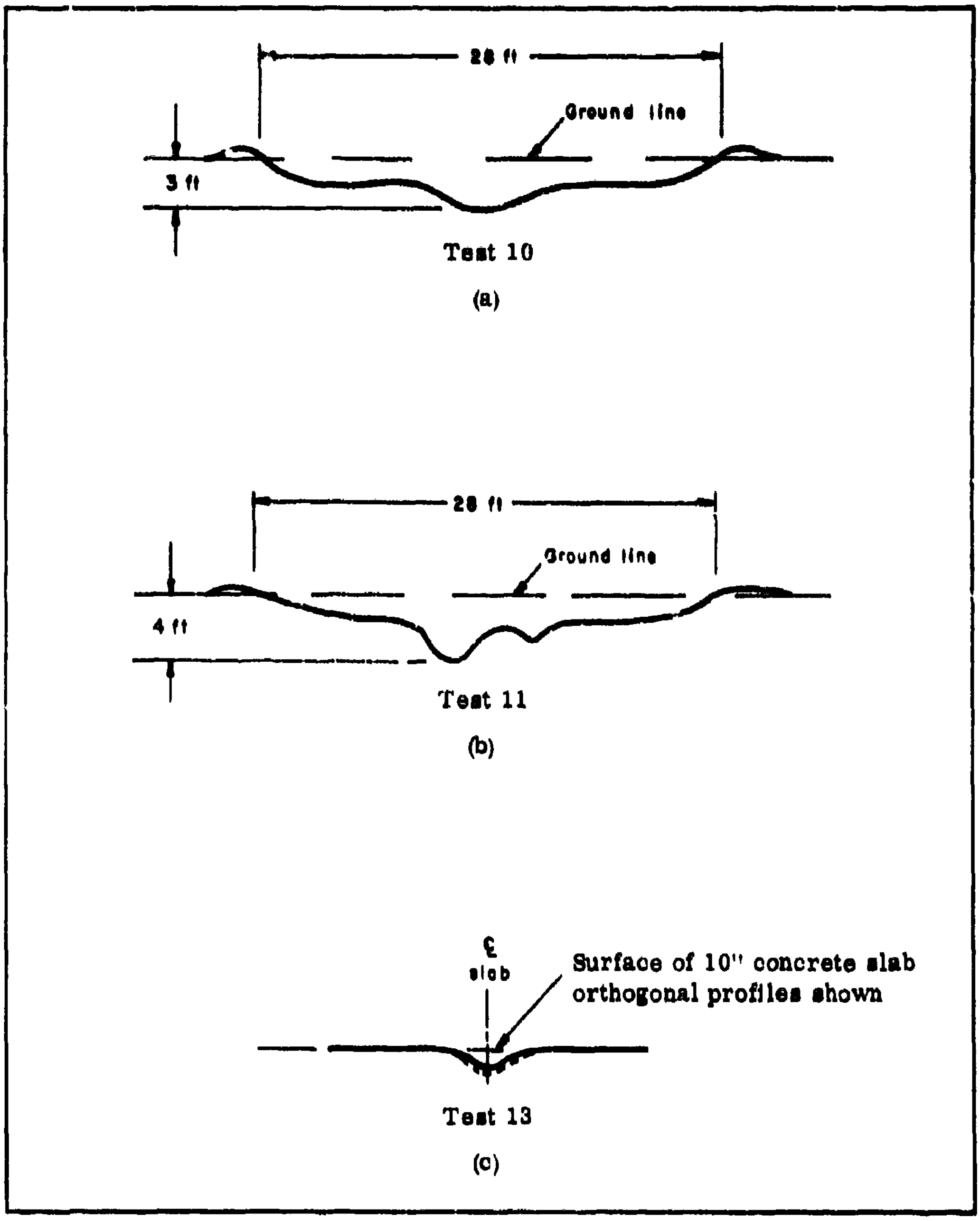


FIG. 9. Crater Profiles for Motor Tests Conducted With Axes Vertical.

Test conditions for test 16 were similar to those of test 13; that is, a 96-lb C-4 explosive booster was used; and an 8,870-lb Class 7 second-stage motor was placed on top of the 15,200-lb, Class 2 first-stage motor. However, a shortened interstage, which provided only 3 in. of separation between the propellants, was used. Burning fragments were thrown out to about 2,000 ft and, again, there was no significant crater. The estimated terminal yield was approximately 83 percent.

Tests 14 and 15

A three-stage Wing 1 Minuteman missile was used in each of these tests, with a 48-lb C-4 booster placed on top of the third stage. The first stage of this missile contains 45,040 lb of Class 2 propellant, the second stage 10,250 lb of Class 2 propellant, and the third stage 3,665 lb of Class 7 propellant. In test 14, the normal interstage hardware, which provides clearance of 32 in. between the closest point on the bulkhead between the first and second stages and 18 in. between the second and third stages, was used. The third stage (donor) and part of the second stage (acceptor) were consumed in the explosion. The first stage fell over and burned for approximately 4 minutes. There was no crater. The estimated terminal yield, based on the total weight of 58,955 lb of propellant, was 13 percent. However, if only the weight of the second and third stages (13,915 lb) is considered, since the first stage apparently merely burned, the estimated pressure yield is 53 percent.

In test 15, shortened interstage hardware was used, which reduced the clearance between the first and second stages to 6 in. and the clearance between the second and third stages to 9 in. All other test conditions remained the same as for test 14. Propellant fragments were thrown about 800 ft, and aluminum fragments were thrown to about 500 ft. The first stage fell over and burned, and there was no apparent crater. The estimated pressure yield, based on the total propellant weight of 58,955 lb, was 16.5 percent, not significantly different from that of the same weight of propellant for test 14.

FRAGMENT STUDIES

Only those tests involving motors with metal casings resulted in significant fragment debris. After test 13, a detailed search for fragments was made in 200-ft^2 areas laid out along the two gage lines in 20-ft radial increments. A plot of frequency of fragments per 100 ft^2 versus ground range is shown in Fig. 10, in which one curve is plotted for each gage leg and a third is plotted to show the combined data for both legs. Figure 11 shows a corresponding summary

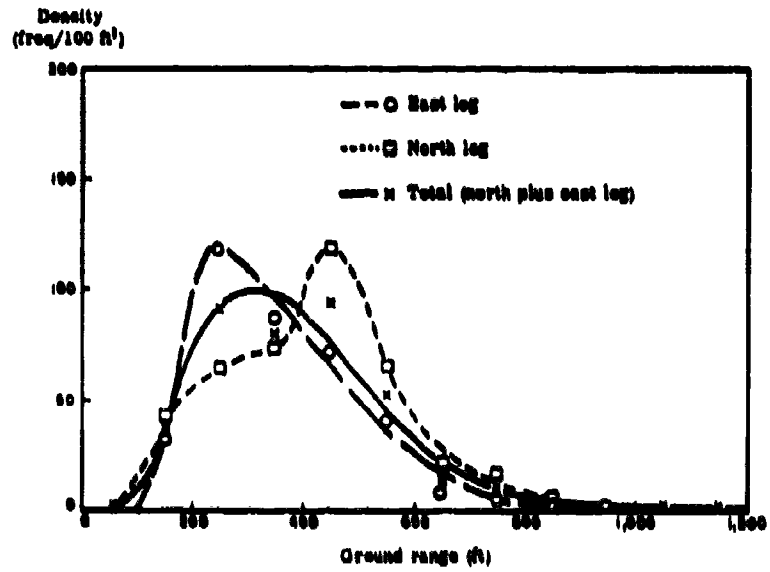


FIG. 10. Fragment Density by Frequency Versus Ground Range for Test 13.

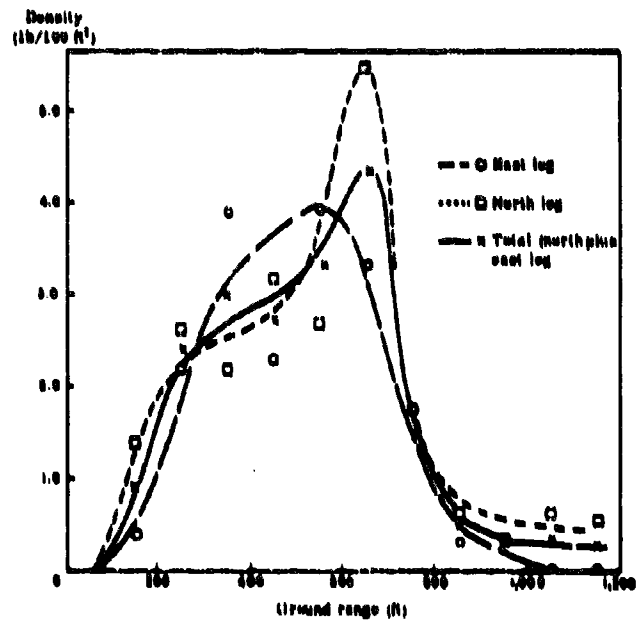


FIG. 11. Fragment Density by Weight Versus Ground Range for Test 13.

based on total weight of fragments per 100-ft^2 area. A comparison of the two sets of data indicates that the larger-size fragments were found at the greater ground distances. A search of the entire area revealed that the maximum ground range for any fragment from this test was 2,510 ft.

For the remainder of the tests, less detailed information was available. Figure 12 shows photographs of individual fragments found after test 8, but a detailed map was not available. Eighteen large pieces of debris were found after test 14 at ground ranges out to about 800 ft. Included were pieces of the second stage. Fourteen large fragments were found after test 15, at a maximum ground range of about 600 ft. Included in fragmonts from this test was a part of the bottom of the third stage.

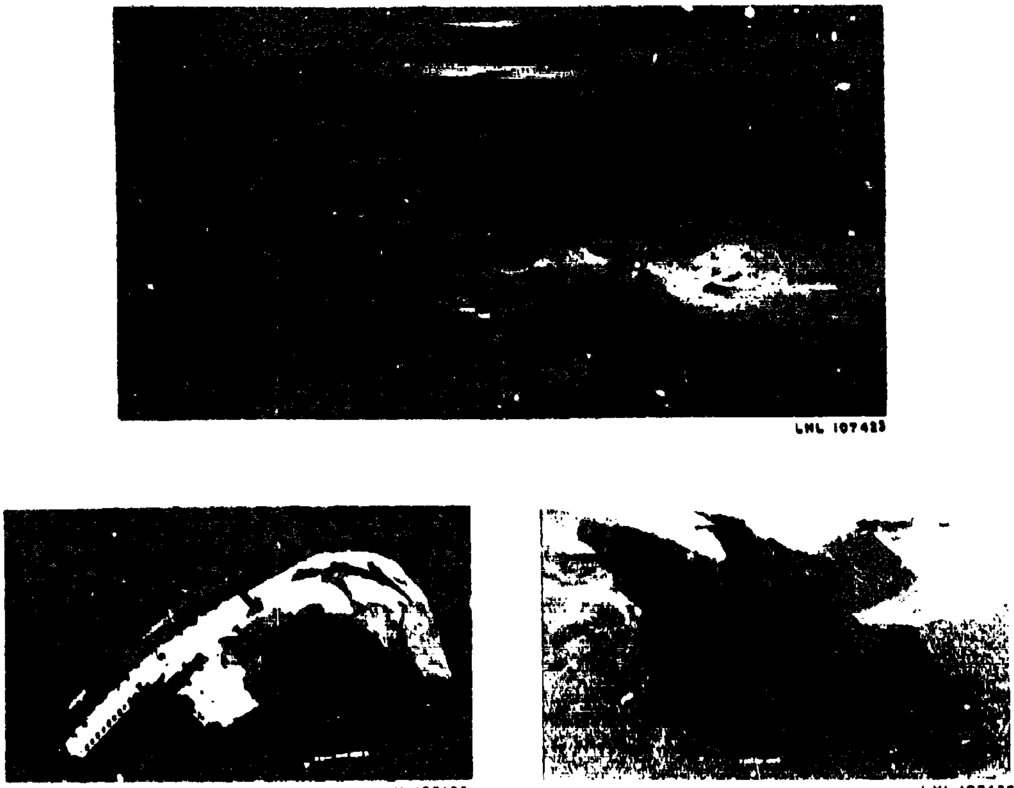
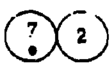
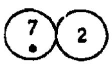
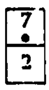
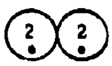
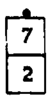


Fig. 12. Photographs of Some Individual Fragments Found After Test 8.

OBSERVATIONS AND CONCLUSIONS

To enable comparison of the data from the seven earlier tests (summarized in Table 2) with the data from the nine tests described in this report, certain of the explosive yield values reported in Ref. 1 have been reevaluated, applying the terminal yield estimation procedures used for the later tests (described on p. 11).

TABLE 2. Summary of Tests From Reference 1

Test No.	Test configuration	Propellant		Terminal yield (%)
		Class	Weight (lb)	
1		2	7,250	25
2		7	7,360	140
3		7 2	7,360 7,250	123
4		7 2	7,360 7,250	110
5		7 2	7,360 7,250	114
6		2	14,500	40
7		7 2	7,360 7,250	107

Class 7 Propellant Tests

During the two test series, the following four tests were conducted in which Class 7 propellants were tested alone:

Test No.	Propellant weight (lb)	Booster Location	Booster Weight (lb)	Terminal yield (%)
2	7,360	Internal	96	140
9	3,665	Internal	48	125
10	3,665	External	50	120
11	7,330	External	50	124

It will be noted, that the yields from the three tests in which the booster weighed approximately 50 lb were about the same, and that the yield from the test with the 96-lb booster was slightly, but probably not significantly, larger.

Class 2 Propellant Tests

The following three tests were conducted with Class 2 propellants tested alone:

Test No.	Propellant weight (lb)	Booster Location	Booster Weight (lb)	Terminal yield (%)
1	7,250	Internal	96	25
6	14,500	Internal	96*	40
8	14,500	Internal	48*	1.4

*In each of two motors

A single motor was used in test 1, and two motors were placed side by side for tests 6 and 8. In tests 1 and 6, each motor contained a 96-lb C-4 booster, and in test 8 each motor contained a 48-lb Aerex booster.

It will be noted that in test 8, with the relatively low detonation velocity explosive, the yield was quite low. The test with one motor and a larger 96-lb booster gave a 25 percent yield, and the test with two motors and the two larger size boosters gave a yield of 40 percent.

Combined Propellant Tests

In tests 3, 4, 5, 7, 12, 13, 14, 15, and 16, a Class 7 motor with booster was used as a donor for a Class 2 motor. Using the terminal yields from these nine tests, an estimate has been made of the explosive yield of the Class 2 motors by deducting the estimated yields of the Class 7 donors from the total measured yields, as illustrated below. (The estimated Class 7 yield used was 127 percent, or the average of the yields from tests 2, 9, 10, and 11.)

Test No.	Class 2 propellant weight (lb)	Class 7 propellant weight (lb)	Booster weight (lb)	Terminal yield (%)	Estimated yield Class 2 propellant (%)*
3	7,250	7,360	96	123	119
4	7,250	7,360	96	110	93
5	7,250	7,360	96	114	101
7	7,250	7,360	100	107	87
12	7,250	3,665	48	105	94
13	15,200	8,870	96	73	41
14	10,250 & 45,040	3,665	48	13	30**
15	10,250 & 45,040	3,665	48	16.5	50**
16	15,200	8,870	96	82	56

$$^{*}\text{Yield Class 2} = \frac{(\text{Total propellant weight})\ (\text{Terminal yield}) - (1.27)\ (\text{Class 7 weight})}{\text{Class 2 propellant weight}}$$

**Only the second and third stage propellant weight was used in this computation

It will be noted that the estimated yields for the Class 2 propellant in tests 3, 4, 5, 7, and 12, in which there was intimate contact between the motors, are remarkably similar, ranging from 87 to 119 percent. Either the two motors were laid side by side in contact or, when stacked one on top of the other, their domes were in contact. In tests 13 through 16, however, the motors were not in intimate contact, and the acceptor yields (Class 2 propellant) were considerably lower. In test 13, normal interstage hardware was used, which separated the propellants by 14 in. The acceptor yield of this test was 41 percent. In test 16, the same type motors were used with shortened interstage hardware, which separated the propellants by 3 in., and the yield was 56 percent. Similarly, in test 14, where a separation distance of 18 in. was used between the second and third stages, the acceptor yield was 30 percent, and in test 15, with the same type of second and third stage motors and a separation distance of 9 in., the yield was 50 percent.

SUMMARY

The results obtained to date indicate that, under the stimulus of a relatively small (50 to 100 lb) explosive booster, the Class 7 motors tested are capable of producing blast yields averaging 130 percent of TNT.

Under similar test conditions, the Class 2 motors tested produced yields as large as 40 percent.

When a Class 7 motor with an explosive booster is placed in intimate contact with a Class 2 motor, yields, based on the total propellant weight, ranged from 105 to 123 percent. The estimated yields for the Class 2 motors alone in these tests ranged from 87 to 119 percent.

One interesting trend is the reduction in yield when the Class 7 and Class 2 motors are not in intimate contact, but are separated by very small distances.

Appendix

PEAK OVERPRESSURE AND POSITIVE-PHASE-IMPULSE DATA

Peak overpressure and positive-phase-impulse data for the six high-explosive and nine motor hazard tests conducted during this series are presented in Tables 3 through 17. Figures 13 and 14 show crater profiles from the high-explosive tests, Fig. 15 includes photographs taken after the high-explosive tests, and Fig. 16-18 are post-test photographs of the motor hazard tests.

TABLE 3. Peak Overpressure and Positive-Phase-Impulse Data From High-Explosive Test 1C

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	131	86.2	605	375
	134	73.2	662	344
110	63.1	50.4	323	260
	109	46.6	642	223
150	17.8	18.5	198	215
		18.2		122
210	5.80		108	
340	2.81*	2.20*	54.6	49.0
520	0.97*	1.26*	30.9	37.3
	1.11*	0.81*	30.0	
880	0.49*	0.71*	19.2	55.4
	0.60*		26.0	
1400	0.32	0.31	15.0	13.3
	0.35	0.43	15.6	17.6
2000	0.22	0.28		12.4

*Non-classical multiple peak trace--number quoted is highest peak

TABLE 4. Peak Overpressure and Positive-Phase-Impulse Data From High-Explosive Test 2C

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	274	458	1280	
	337	323	1273	
110	144	204	795	813
	145	208	721	610
150	56.8	63.8	378	436
	53.3	65.5	316	366
210	15.3	23.6		262
	19.7			
340	5.73*	5.34*		110
		5.82*		223
520	2.26*	3.14*		122
	2.15*	1.90*		
880	1.22*	1.01*		59.3
1400	0.56*	0.56*		59.7
	0.55*	0.57*		38.3
2000	0.63**	0.47*		31.0

*Non-classical multiple peak trace--number quoted is highest peak

TABLE 5. Peak Overpressure and Positive-Phase-Impulse Data From High-Explosive Test 3C

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	374	381	1273	2026
	391	284	1554	1705
110	127	109	661	963
	117	101	715	666
150	30.6	37.0	294	392
	44.6	44.5	317	402
210	8.33*	4.49*	143	
	8.10*			
340	4.13*	5.16*	149	135
	2.80*	3.73*		
520	1.08*	1.43*		49.8
	1.33*			
880	0.62*	0.85*		37.1
	0.59*	0.94*	17.7	21.3
1400	0.46	0.44	24.3	45.7
	0.51	0.66	24.6	30.9
2000	0.39	0.36	17.7	18.5

*Non-classical multiple peak trace--number quoted is highest peak

TABLE 6. Peak Overpressure and Positive-Phase-Impulse Data From High-Explosive Test 4C

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	204	133	564	750
	272	133	840	650
110	139	124	611	485
	110	86.4	606	397
150	49.0	31.3	229	232
	41.6	40.3	267	199
210	9.64	10.0	143	163
	8.98	11.5		
340	4.71*	4.99*	141	139
	3.98*	3.44*	108	95.4
520	2.14*	1.36*	53.7	57.0
	2.05*			
880	1.01*	0.65*	31.7	27.7
	1.04*	0.71*	29.6	31.6
1400	0.62*	0.42*	21.3	41.1
	0.78*	0.48*	27.3	
2000	0.40*	0.38*	17.0	22.6

*Non-classical multiple peak trace--number quoted is highest peak

TABLE 7. Peak Overpressure and Positive-Phase-Impulse Data From High-Explosive Test 8C

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	PEAK OVERPRESSURES (psi) North	IMPULSE (psi-msec) East	IMPULSE (psi-msec) North
80	258	222	1043	923
	278	299	923	814
110	156	171	718	692
	169	153	675	700
150	67.7	66.3	386	479
	65.5	65.2	348	406
210	22.0	18.5	278	265
		17.8		281
340	6.46	7.78	174	182
	6.95	7.62	140	146
520	2.93	3.00	92.0	119
	2.68	2.50	82.5	87.1
880	0.95	1.65	50.9	
	1.03	1.19	39.5	47.0
1400	0.45	0.54	20.9	27.2
	0.72	0.58	40.2	31.4
2000	0.37	0.40	25.1	28.5
2500	0.29	0.44	17.4	29.4

TABLE 8. Peak Overpressure and Positive-Phase-Impulse Data From High-Explosive Test 6C

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi · msec) East	North
110	31.5			
150	28.0		275	
	16.7		244	
210	13.1	11.9	188	191
		9.37		
340	4.72	4.81	119	121
	4.35	4.70/4.59	112	107/117
520	2.11	2.30	60.6	66.3
	2.43	2.39/2.44	79.9	91.1/85.0
880	1.32	1.43	49.5	54.1
		1.41		40.6
1400	0.87	0.96	38.6	46.2
		0.79		39.9
2000	0.67		22.4	
2800	0.43		23.6	

TABLE 9. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 8

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	9.33			
110	2.19	1.81	36.0	16.9
				30.7
150	2.58	1.13		
	2.31	1.79		
210	1.58		15.7	
	1.56		20.7	
340		0.74		7.01
	0.67	0.45	9.05	4.70
520	0.33	0.27	4.63	3.06
		0.31		4.13
880	0.21	0.16	3.44	2.38
		0.20		2.67
1400	0.20	0.17	3.63	2.66
2000	0.06	0.04	1.70	1.08

TABLE 10. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 9

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi)		IMPULSE (psi- msec)	
	East	North	East	North
80		120	700	
110	77.2	31.2	490	290
	53.5		365	
150	12.2		236	211
	15.3	15.7	208	104
210	5.86	5.26	93.5	92.0
	5.93	6.37	88.6	125
340	4.79	2.60	76.9	57.0
	2.73	4.17/2.88	49.9	106/58.5
520	0.99	1.37	29.5	36.6
	1.78	1.49	53.8	37.1
880	0.71	1.04	21.6	29.8
	0.60	1.09	35.9	32.4
1400	0.45	0.43	22.0	19.5
	0.59	0.65	22.1	23.5
2000	0.16	0.27	9.13	10.2
	0.17		7.31	

TABLE 11. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 10

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	PEAK OVERPRESSURES (psi) North	IMPULSE (psi-msec) East	IMPULSE (psi-msec) North
110	29.5		316	
	24.2		333	
150	12.2	11.8		228
	13.0			
210	6.12	7.02	90.3	129
	6.38	6.07	93.4	85.6
340	3.35	2.64	72.9	53.2
	2.62	3.20/2.51	50.4	108/49.9
520	1.88	1.20	65.3	31.4
	1.17	1.10	25.9	21.5
880	0.86	0.80	21.6	24.4
	0.83	0.92	38.8	24.7
1400	0.51	0.38	19.4	15.2
	0.54	0.54	20.4	19.3
2000	0.17	0.22		
	0.18	0.22	7.01	8.13

TABLE 12. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 11

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	141	92.0	915	746
110	64.5	69.4	684	590
	47.5	59.8	370	671
150	24.3	25.6	413	464
	26.8	24.5	481	397
210	10.6	11.7	165	150
	9.55	13.0	145	207
340	5.19	4.17	125	98.5
	3.64	3.83/5.34	89.6	87.7/146
520	2.29	1.71	108	49.9
	1.77	1.85	47.5	53.6
880	1.09	1.08	60.4	37.1
	1.11	1.20	33.3	41.3
1400	0.61	0.53	28.1	24.9
	0.82	0.70	31.1	30.3
2000	0.26	0.37	9.29	17.6
	0.21	0.29	11.6	13.2

TABLE 13. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 12

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi)		IMPULSE (psi- msec)	
	East	North	East	North
80	80.0	80.0	500	
	78.6		459	505
110	57.0		277	
	55.3		313	
150	16.2	37.1	158	307
	20.0	37.5	155	277
210	10.5	9.67	167	186
	10.6	6.11	152	198
340	4.54	4.38	151	130
	4.98	4.82	119	136
520	2.65	2.38	62.4	79.8
	2.61		65.3	
880	1.19	1.17	40.4	35.3
	1.24	1.49	31.4	42.4
1400	0.67	0.62	29.7	
	0.67	0.64	32.6	49.9
2000	0.47	0.49	28.7	28.1

TABLE 14. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 13

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	PEAK OVERPRESSURES (psi) North	IMPULSE (psi-msec) East	IMPULSE (psi-msec) North
110	47.0	65.4	447	635
		69.3		635
150	24.4	26.1	254	262
210	12.8	16.1		228
	14.4			
340	7.01	7.18	118	
	6.27		166	
520	3.18	3.07	110	100
880	1.49	1.37	47.5	48.1
1400	0.74	0.72	36.4	39.4
2000	0.52	0.56		34.2
2500	0.40	0.38		13.2

TABLE 15. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 14

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	76.1	67.0	261	288
110	32.4	28.5	245	233
150	10.5		140	
210	7.79		130	
340	3.92		59.2	
520	2.11		41.4	
880	0.82	1.16	21.0	35.5
1400	0.53	0.66	17.6	21.3
2000		0.42		19.0
2500	0.22	0.30	10.0	12.9

TABLE 16. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 15

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
80	94.1		636	
110	36.6	29.9	266	219
150	14.9	17.1	136	177
210	10.5	12.5	134	140
340		4.24		80.1
520		2.24		54.4
880		1.27		16.7
1400	0.61	0.76	16.9	27.8
	0.54	0.67	19.5	23.6
2000	0.40	0.42	15.9	17.4
2500	0.28	0.34	12.2	13.1

TABLE 17. Peak Overpressure and Positive-Phase-Impulse Data From Motor Hazard Test 16

GROUND RANGE (ft)	PEAK OVERPRESSURES (psi) East	North	IMPULSE (psi-msec) East	North
110	60.3		439	
150	27.5	30.7	326	344
210	15.4	16.7	251	237
340	7.03	6.94	169	171
520	3.11	3.50	111	110
	3.49	3.22	104	104
880	1.50	1.72		54.7
	1.73	1.89	76.0	63.2
1400	0.91	0.98	28.5	55.8
	0.82	1.03	39.9	50.9
2000	0.47	0.58	30.1	36.1
	0.43	0.50	28.2	28.6
2500	0.34	0.43	24.8	

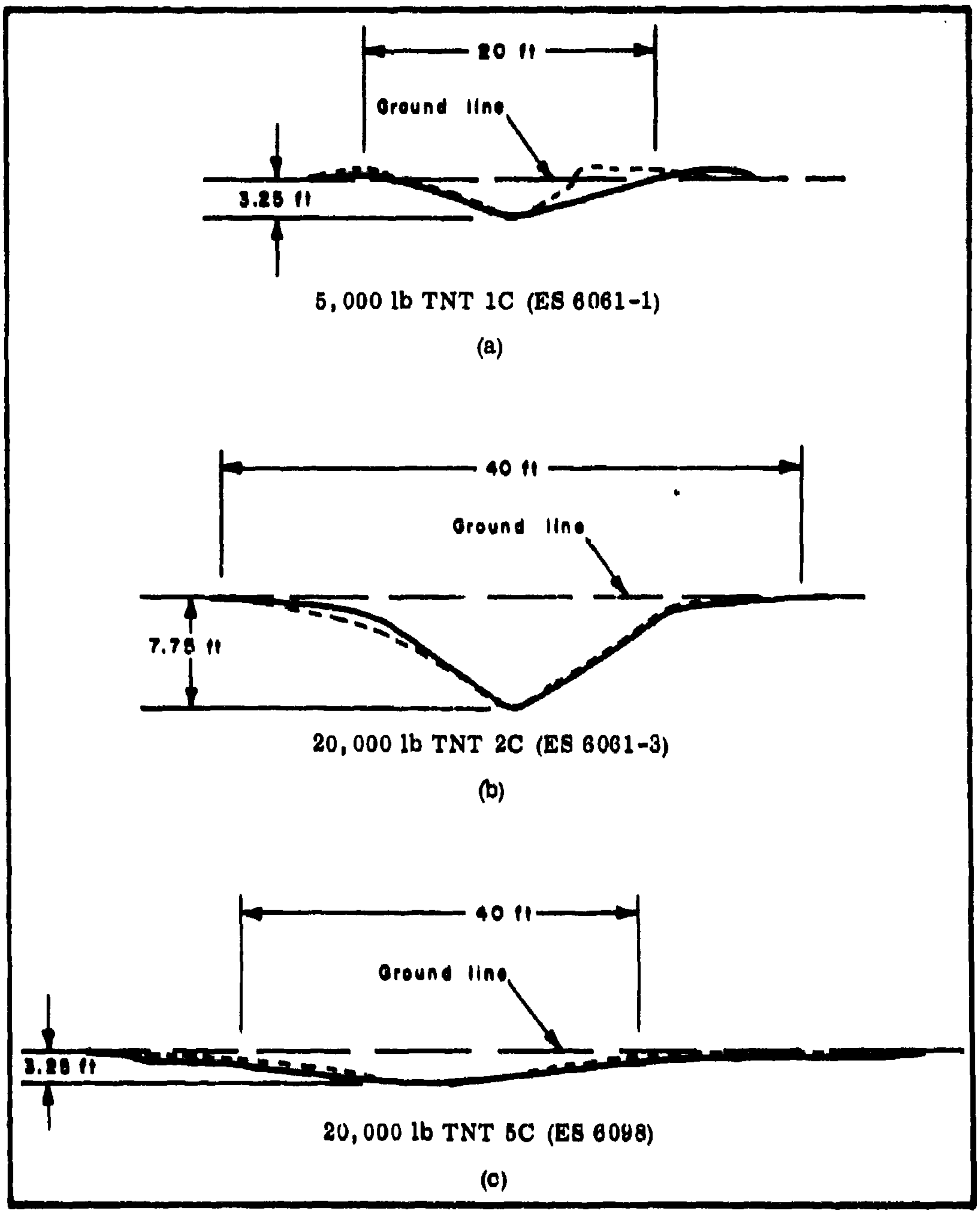


FIG. 15. Orthogonal Profiles of Craters From Tests 1C, 2C, and 5C.

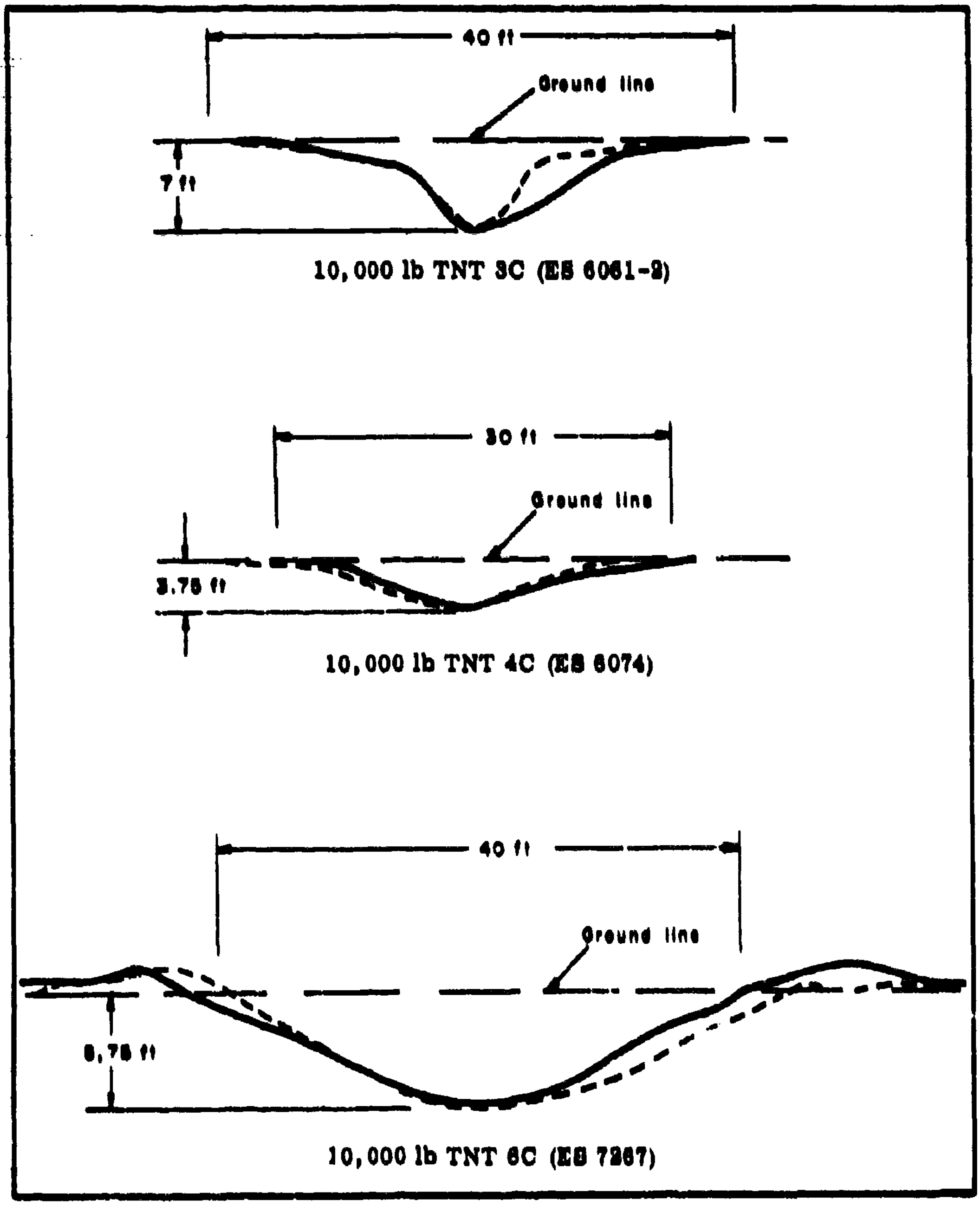


FIG. 14. Orthogonal Profiles of Craters From Tests 3C, 4C, and 6C.

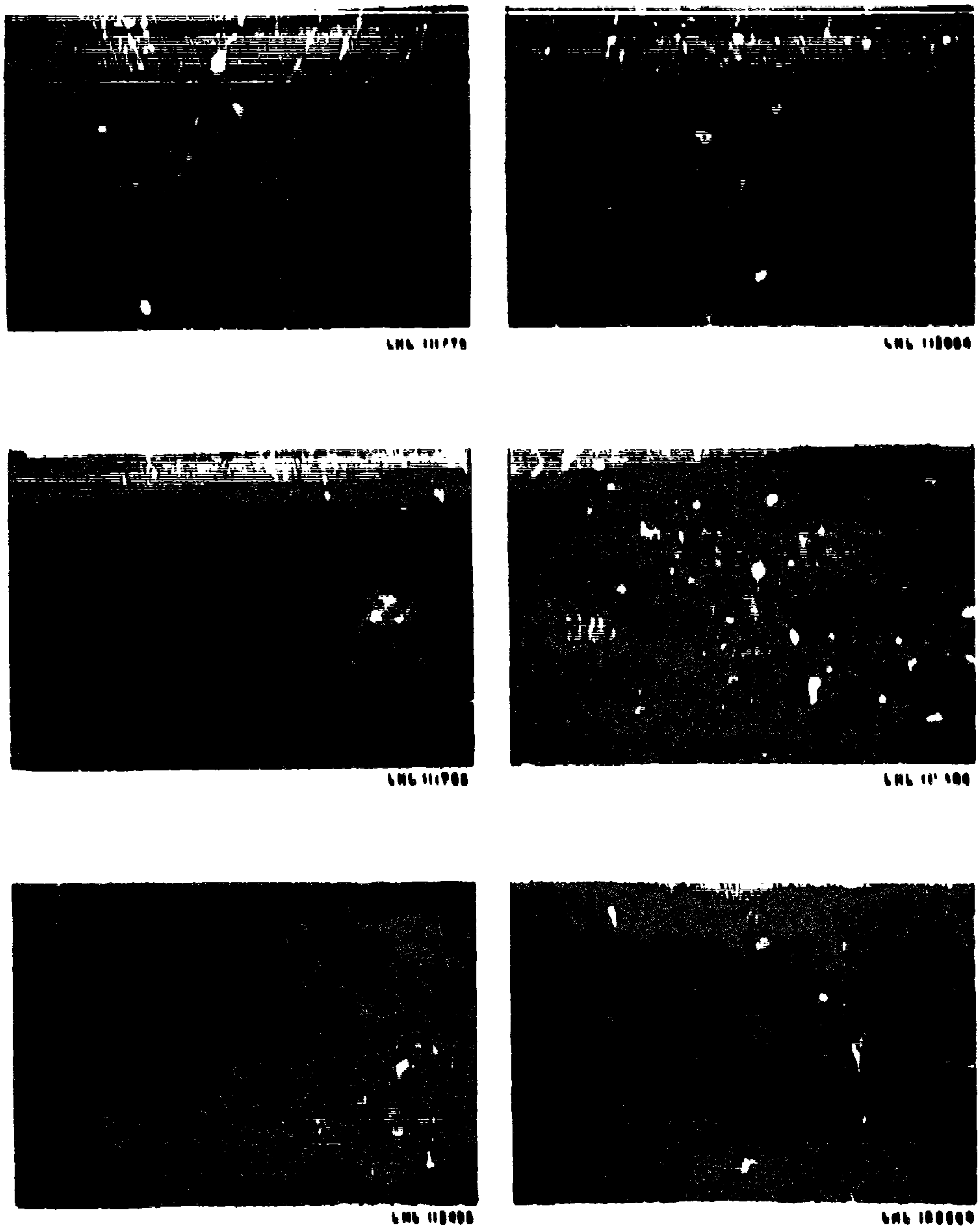


FIG. 18. Posttest Ground Zero Photographs for TNT Reference Tests 1C Through 6C.

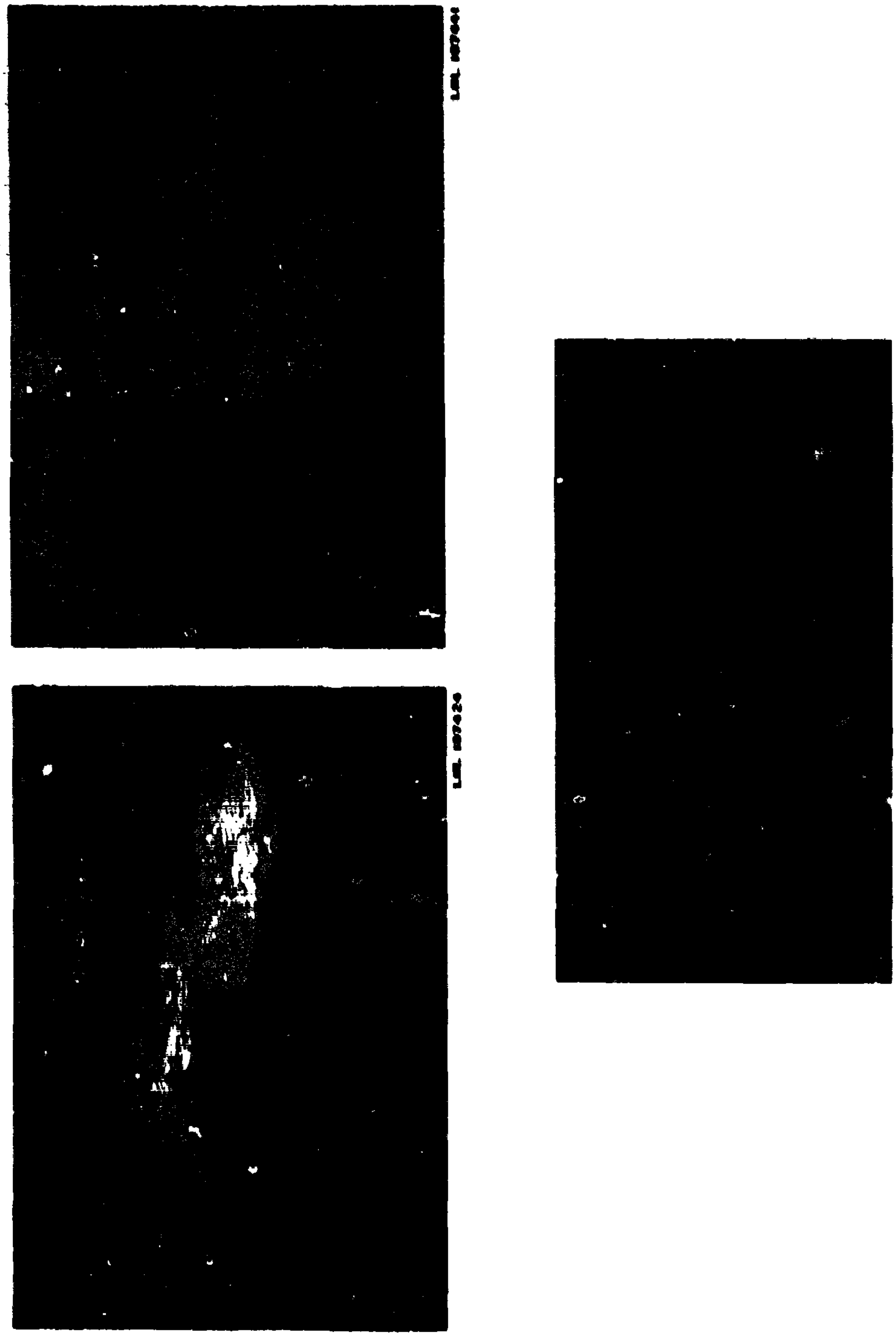


FIG. 16. Postshot Ground Zero Photographs for Tests 8, 9, and 12.

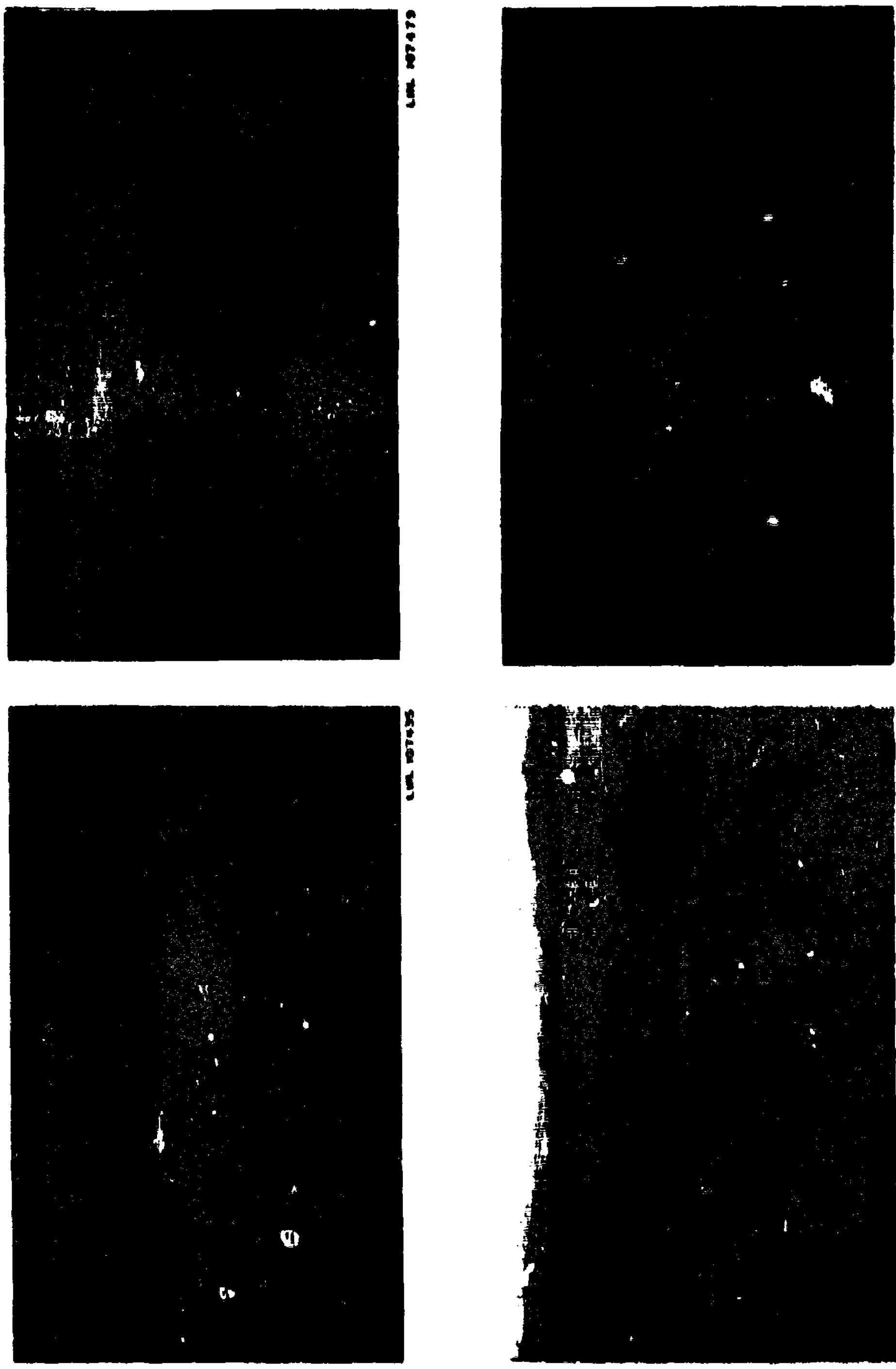


FIG. 17. Posttest Ground Zero Photographs for Tests 10, 11, 13, and 16.

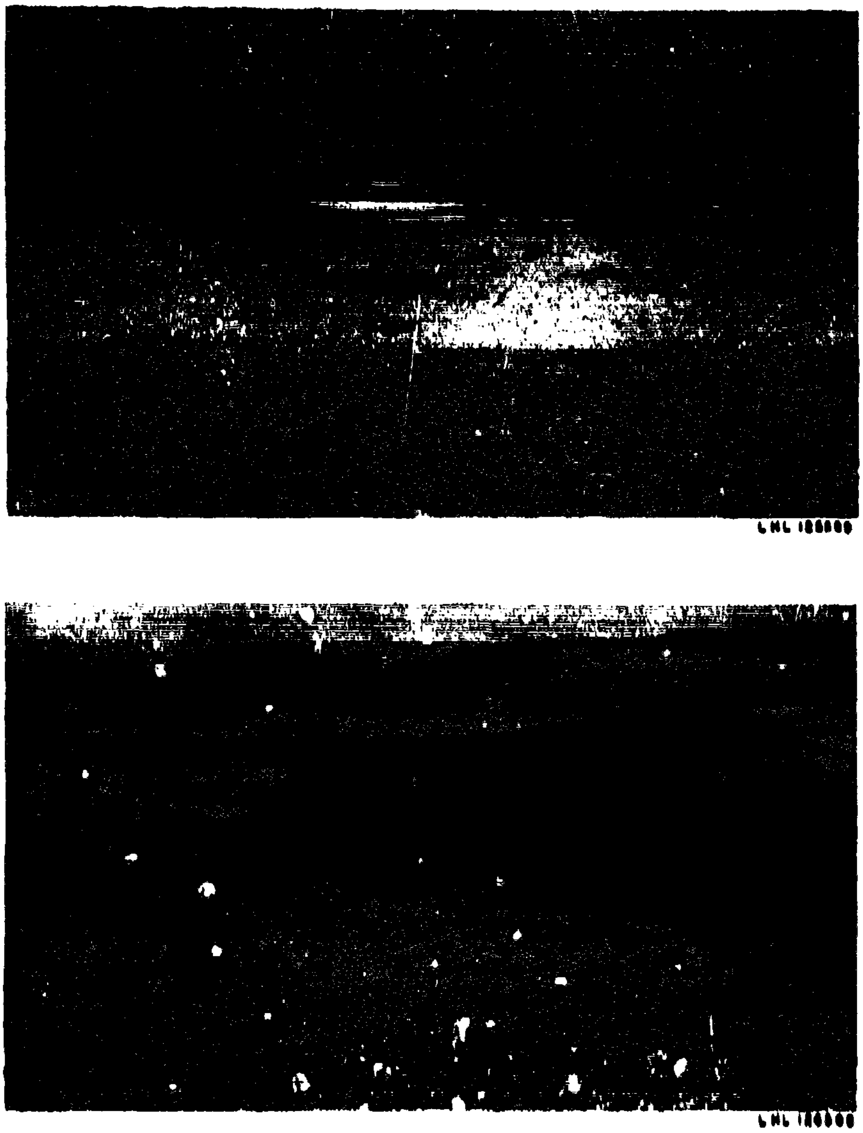


FIG. 18. Posttest Ground Zero Photographs for Tests 14 and 15.

REFERENCES

1. Naval Ordnance Test Station. High Explosive Equivalency Tests of Rocket Motors, by F. H. Weals and C. H. Wilson. China Lake, Calif., NOTS, November 1965. NOTS TP 3910.

2. Ballistics Research Laboratory. Air Blast Parameters Versus Distance for Hemispherical TNT Surface Bursts. Aberdeen Proving Ground, Md., BRL, September 1966. BRL Report No. 1344.

3. Defense Atomic Support Agency. Operation SNOW BALL Project Descriptions, Volume 1. Washington, D.C., DASA, July 1964. DASA Data Center Special Report 24-1, DASA 1516-1 (AD 441 974).

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Weapons Center China Lake, California 93555	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP --

3. REPORT TITLE

HIGH EXPLOSIVE EQUIVALENCY TESTS OF LARGE SOLID PROPELLANT MOTORS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

URS Systems Corporation

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1968	46	3

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) NWC TP 4643
b. PROJECT NO. Jointly funded by the Army, Navy, Air Force, DASA, and NASA	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	--

10. DISTRIBUTION STATEMENT

This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of the Naval Weapons Center.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
--	Department of Defense Armed Services Explosives Safety Board Washington, D.C. 20315

13. ABSTRACT

From June 1965 to February 1968, nine solid propellant motor hazard tests and six high-explosive tests were conducted at the Naval Weapons Center, China Lake, to evaluate the explosive potential of large Class 2 and Class 7 solid propellant motors. Test parameters which were varied during the program were propellant type, weight, and orientation and explosive booster type and location. The results of these tests, combined with data from seven previous tests conducted at NWC, indicate that, under the stimulus of a relatively small (50 to 100 lb) explosive booster, the Class 7 motors tested are capable of producing blast yields averaging 120% of TNT, and the Class 2 motors produced yields as large as 40%. When a Class 7 motor with an explosive booster was placed in intimate contact with a Class 2 motor, yields, based on the total propellant weight, ranged from 105 to 125%. The estimated yields for the Class 2 motors alone ranged from 87 to 119%. In tests in which a Class 7 motor with an explosive booster was placed near, but not in intimate contact with, a Class 2 motor, the estimated yields for the Class 2 motors alone ranged from 30 to 50%, considerably lower than the yields obtained in the intimate-contact tests. The separation distances used ranged from 3 to 18 inches.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Equivalency tests						
High explosive propagation studies						
Motor tests						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)